1981-09

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http://hdl.handle.net/10945/20467

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THESIS

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by

Otfried Hartmut Bapistella

September 1981

Thesis Advisor: J. G. Taylor

Approved for public release, distribution unlimited

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
Concepts of Combat Modelling for Long-Range Air Armament Planning and Their Implmentation in the "Tactical Air War Analysis Game"

5. TYPE OF REPORT & PERIOD COVERED
Master's Thesis
September 1981

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Otfried Hartmut Bapistella

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93940

12. REPORT DATE
September 1981

13. NUMBER OF PAGES
65

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release, distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Force Planning
Firepower-Score Approach
Monte Carlo Simulation
Military Production Function
Mathematical Modelling
Resource Allocation
Transferability of Models

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1981

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This thesis describes the conceptual background and the main problems encountered in force-structure planning. The model structure of the "Tactical Air War Analysis Game" (TAWAG) is reviewed and improvements and enrichments are proposed. Based on experience from trying to implement this model on the computer of the Naval Postgraduate School, the author makes some recommendations to improve the transferability of models.

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I. INTRODUCTION

A. PROBLEM SETTING

Due to fiscal limitations, defense decision-makers are always concerned with the problem of allocating limited resources to certain projects or weapon systems. The goal is to maximize the effectiveness of existing forces by either reorganizing them, developing new doctrines or procuring new weapon systems. It is easy to find examples in history that the improvement of the effectiveness of one military force due to the implementation of "better" systems forced the opponent to employ countermeasures against the perceived new threat, thus starting what is now known as an "arms race". Improvements in efficiency seem to foster this process. On the other hand, one can argue that it is--at least theoretically--possible to contain an arms race by means of thorough investigation and objective analysis of the capabilities and possible options of both sides involved. This would lead to a reasonable assessment of force-balance conditions and this in turn may result in ending an arms-race. It even might help to reduce forces through mutual agreement on the results of that analysis.

Some of the most often encountered resource allocation issues are: [Ref. 1: p. 2]

- How to assess the capability of a possible opponent and how large should the military forces be to meet the perceived threat?
- What is the (optimal) force structure overall? (Army - Navy - Air Force)

- What is the (optimal) force structure with respect to service branches?

  (Infantry - Tanks - Artillery)

- What is the (optimal) force structure with respect to service specialties?

  (Personnel Support - Logistics)

- What new weapon systems are necessary to close perceived gaps in technological developments?

  (Physical specifications, number, tactical use, C^3-context)

These resource allocation problems are not new, they were principally the same throughout history [Ref. 2]. Different operation plans and changing situations, geopolitically as well as on the battlefield, require reorganization of forces with varying urgency. The skill of the military decision-maker is--among others--the ability to select out of the huge number of different possibilities of force aggregations the one which is properly suited to match the task.

Usually the decision made is based upon decision rules which reflect the educational background of the decision-maker, as well as on his experience; e.g., a decision-maker educated in physics or engineering might use concepts or models used there to find a solution for the problem at hand, although the situation he encounters might be obscured by factors not related to physical phenomena. For the problem of analysis versus judgment, see Stockfisch [Ref. 1: p. 4].

In spite of the organizational levels at which the problems are encountered, they almost always are characterized by the same type of structure of antagonistic objectives. This structure principally

consists of interaction processes of measures and countermeasures applied with consideration of own resources and possible reactions of the opponent. This depicts a situation typical for games. Game theory [Ref. 3] focuses on such antagonistic situations. Decision making with conflicting objectives has been modelled by the paradigms of game theory. Game theory addresses both static situations (normal form of game) and dynamic situations (extensive form), and the latter is more germain to modelling of military campaigns as frequently done in defense planning. This leads to interest in differential games. (For the theory of differential games, see Isaaks [Ref. 4].)

It is therefore not surprising that for a long time in history games have been used as devices to enhance the training of present and future military decision-makers. War games were also used for the analysis of military problems. For a short history of military games, see Huber [Ref. 5: p. 24] and McHugh [Ref. 6]. The introduction of electronical data handling devices has increased the speed of calculations and thus enabled the decision-makers to use combat modelling and war games as decision aides for routinely encountered problems. It has also furthered their use as educational media and analytical tools.

B. OBJECTIVE OF THESIS

Modern aircraft with their potentially devastating firepower on the battlefield, and with their ability to reduce reaction times to sudden threats, as well as their inherent capability to be concentrated to form locally and timewise limited air superiority, play an important role, not only for the outcome of a particular ground battle but also for the outcome of wars.

Development of an "optimal" doctrine and exact planning of "optimal" allocation is therefore paramount. These problems foster highly sophisticated, scientific methods. To reduce the risk of decisions, these methods will have to be constantly refined and improved.

The long lead-times for the development of weapon systems and the high cost involved in design, construction, procurement, and maintenance have led to ever-increasing demands for analysis. These investigations have mainly been concentrated on the following two aspects: [Ref. 7: p. 5]

- long-range planning concerning operational design of future aircraft and
- short-range planning concerning the mission assignment of currently procured systems.

Additionally, these efforts are undertaken to prolong the operational "lifetime" of weapon systems to reduce overall costs.

To reduce these possible costs, the "Tactical Air War Analysis Game" (TAWAG) was designed by Taylor and Huber in 1979 [Ref. 7] and later developed by students of the Armed Forces University in Munich, West Germany (Hochschule der Bundeswehr, Muenchen). It models a conventional conflict on theater level, e.g., Central Europe. It can be understood as a framework of hierarchically structured sub-models on different levels of abstraction. TAWAG enables the researcher to study the influence of the variation of deployment strategies of air war systems on the results of ground war.

This thesis describes the conceptual background of TAWAG, reviews the model structure and purposes improvements and enrichments. Based on experience gained from trying to implement this model on the computer

system of the Naval Postgraduate School, the author makes recommendations to improve the transferability of computer models.

II. CONCEPTUAL SETTING

A. MEANS OF INVESTIGATION

The military analyst is usually concerned with one of two problem areas: (1) the long-term planning of force structures or (2) the short-term problem of maximizing the effectiveness of currently available forces. Both problems require some form of modelling of military operations, although the sets of constraints will be different in each of the two cases. Huber proposes the use of three interacting categories of analytical tools [Ref. 5: Annex A, p. 39].

FIGURE 1: Interacting Categories of Analytical Tools

Hierarchical research games are modelled to represent the interactions between the different levels of military environment in combat. They are usually very detailed and need to be complemented by Quick Games, representing the higher levels of the hierarchy, in order to save time when parametric analyses are made on these higher levels. To check estimated parameters and to collect data, field trials are performed.

There exist two principal ways to create models for analysis: data-driven ("bottom-up") and concept-driven ("top-down"). Bottom-up analysis takes technical data of weapon systems, physical constants and mathematical principles and aggregates them through different levels of analysis to a final result. This is the way how, for example, the outcome of an engagement of tank versus anti-tank weapon is modelled. Taking the time necessary to detect and identify the tank as a valid target and the time to aim and fire the weapon, as well as ballistic data of the anti-tank weapon, the probability of hitting the target can be calculated. Taking a (pseudo-) random number, the model can actually predict, if the tank is killed or not. Manual war games and stochastic or deterministic simulations are examples for this method of modelling. The important aspect is that the model is connected to the reality through the use of technical or physical data.

The top-down approach is different in the way that it uses mathematical representations of the effects of sets of weapon systems instead of representing the physical attributes of each individual weapon. The outcomes of military encounters can be determined by manipulating mathematical expressions rather than simulating physical interactions. The most prominent models using this approach are the different forms of the Lanchester equations. The principal difference between data-driven and concept-driven analysis is depicted in Fig. 2.

Modelling of air war operations in the context of an ongoing ground war poses specific problems. Usually the levels of aggregation are an order of magnitude apart. Ground war modelling at theater level is usually aggregated to at least division-level, representing thousands

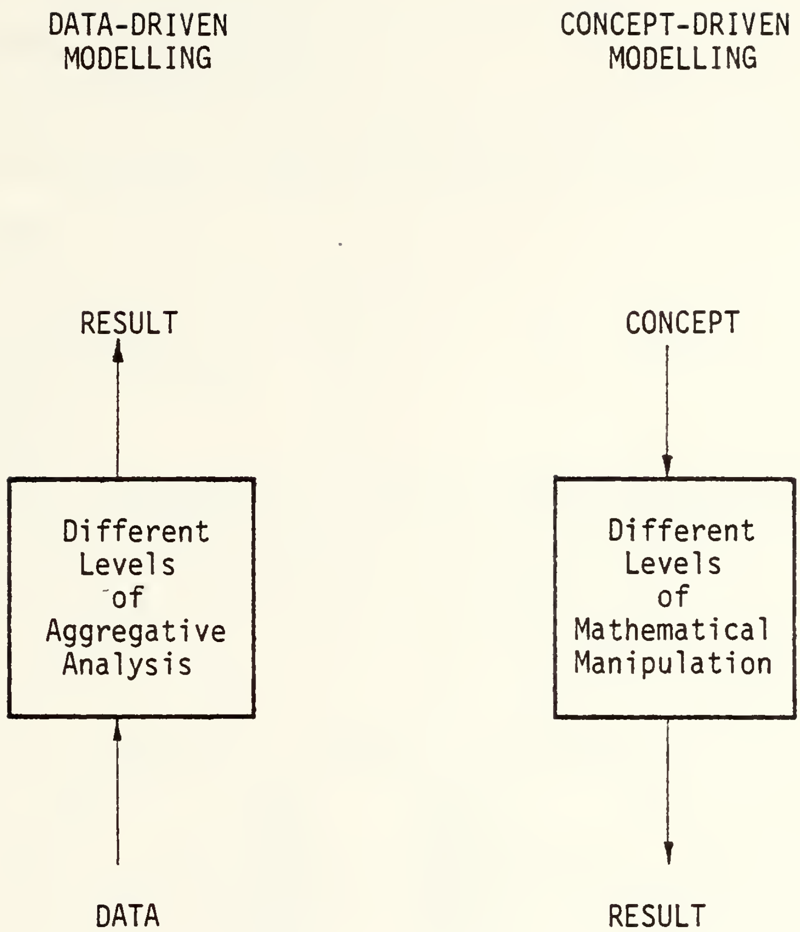


FIGURE 2: Data-Driven Versus Concept-Driven Modelling for Analysis

of weapon systems. Air war has to be modelled on the level of an individual weapon system because of the range, firepower, and ability to fight individually or in large numbers.

The Tactical Air War Analysis Game (TAWAG) presented later in this thesis recognizes these differences.

1. War Gaming and Simulation

The means of analytical investigation depend on the object of interest. Huber identifies three main areas of military activity [Ref. 5: p. 36]:

- Training (T)
- Command and Control (C)
- Planning (P)

Considering each of these areas as the set of all functions and activities performed, they can be depicted as in Fig. 3 below.

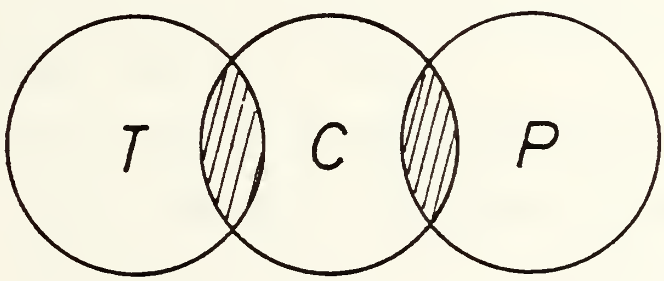


FIGURE 3: Military Activities (see Text)

Training and Command and Control deal with existing forces, and since both functions are performed very often by the same individuals, the intersection of T and C exists. Planning is performed for the future,

taking the present force as a basis, and since the problems for decision-makers are principally identical in both areas, C and P, the intersection of C and P exists.

Each of these three areas fosters different means of investigation:

- War games--assisted and supplemented by field exercises--are used as a training device in T.
- War games and simulations are used in C.
- Analytical models are the primary investigative tools in P.

All three areas are interdependent and the use of the respective research tools is done in an interactive manner as depicted in Fig. 4 [Ref. 5: p. 41].

Military reality can generally be modelled by war games. This insight gave rise to the earliest war games in history, the most prominent of which is Chess. It, in turn, is based on the earlier Tschaturanga, whose origins can be traced to about 2000 B.C. in the Indochinese culture. For more information about the historical development and the use of war games, refer to Huber [Ref. 5: p. 24].

All through history, war gaming was used to train future military decision-makers. It was used also to gain general insights into the nature of war. The principal features of war games are their antagonistic character and the fact that humans interact in the decision-making processes as players and sometimes as umpires. This implies that war games--whether computer-assisted or not--are usually not a feasible means of systematic research, since the results which often depend on personal preferences or experiences of players and umpires are not

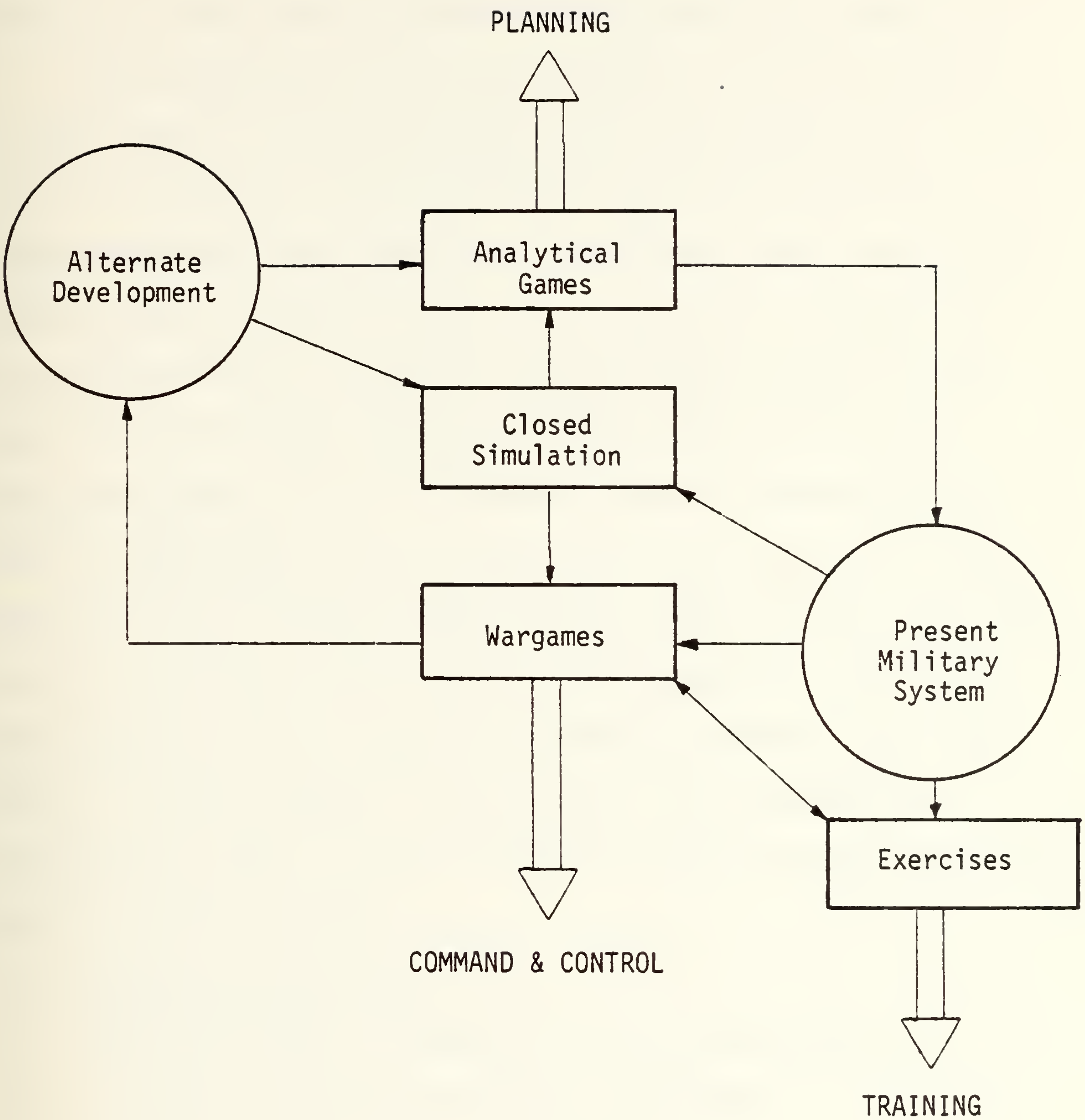


FIGURE 4: Interactive Use of Research Tools

always reproduceable. The necessary consumption of usually scarce resources, like personnel and time, makes the analysis of different alternatives in the course of gaming actions almost always infeasible.

War simulations--since they represent, as the name implies, all minute details--are analog models of military encounters. The effort of bookkeeping of all the details has been facilitated by the introduction of fast digital computers. There exist machine-simulations and simulations with human interaction. Simulation is probably the most widely used means of military analysis, notwithstanding the fact that there exist profound problem areas like the notorious line-of-sight establishment. In the military environment, Monte Carlo Simulations are widely used to model random events like infantry fire-fights. Simulations are particularly useful for the studies of these small-scale encounters, since they contain lots of details, which in turn necessitate large data bases and significant amounts of computer time. Additionally, the establishment of these models, their adjustments to varying research topics and the maintenance of the data bases are rather expensive and time consuming.

2. <u>Mathematical Modelling</u>

Analytical models are characterized by two main features:

- the lack of human participation during runs
- the transparency of their structures.

The first feature facilitates run-to-run reliability, e.g., results can be reproduced simply by using the original inputs. Historically, the first analytical model consisted of the set of differential equations proposed by Lanchester in 1914 as a mathematical formulation of combat

engagment between two homogeneous forces in an attempt to justify the principle of concentration under "modern" war conditions.

In contrast to the aforementioned Monte Carlo simulations, which are used exclusively for small-scale encounters, Lanchester-type models have been implemented successfully for the whole spectrum of combat activities, from company-sized units up to theater-level operations. These models are one of very few feasible approaches for assessing attrition at division level and above. Using numerical approximation techniques, today's models of theater-level warfare can be used to gain insights in the dynamics and dependencies of these combat actions.

B. LARGE SCALE MODELLING

1. Firepower-Score Representation Versus Monte Carlo Simulation

a. Firepower-Score Representation

The concept of firepower-score or firepower-index arises from the fact that very rarely--if at any time at all--military operations were performed with only one type of weapon system on each side, but rather with a mix of different weapon systems, the combination of which often turned out to be crucial for the success, e.g., Hannibal used not only a combination of swordsmen, archers, and chariots--those were known to the Romans too--but also elephants, which gave him the edge at Cannae (218 B.C.).

Implicit in this kind of approach are the ideas of "capability", "power", "effectiveness" or "utility". "Firepower" is often used as a surrogate for these, although the word can be misunderstood. The central issue, however, is that conventional military operations involve the combined use of different specialized forces and that this

requires evaluation in the context of a given scenario. This evaluation provides the ingredients for an index number.

The terms "firepower-score" and "firepower-index" should not be used interchangeably, because the first refers to the military value of a single weapon system, whereas the latter refers to an aggregation of different weapon systems and their combined military value Ref. 8 . Although many firepower-score methods claim that the numerical value of the "score" of a certain weapon or weapon system is determined as the product of a measure of the single-round lethality and the expected expenditure of ammunition or other resources during a fixed period of time, actually varying amounts of subjectivity are involved [Ref. 8: p. 88].

TABLE I

Firepower-Index Assessment

Weapon	Number	Firepower -Score	Contribution to FP-Index
Rifle M16, 5.56mm	6000	1	6000
MG M-60, .3 cal	150	6	900
MG M-2, .5 cal	250	10	2500
Mortar, 81mm	50	20	1000
Howitzer, 155mm	50	40	2000
Tank M60A2	200	100	20000
Total Firepower-Index:			32640

(from: [Ref. 8: p. 87])

In large-scale combat modelling, the fire-power indices are widely used as a surrogate for unit strength when solving one of the following problems:

- determination of engagement outcomes
- assessment of casualties (or rather their equivalent in firepower indices)
- determination of front-movement

This is usually done in two successive steps; firstly, the aggregation of forces is made to determine a total firepower index for each side and the force ratio of the indices of attacker and defender, and secondly, the determination of mutual attrition. The latter involves consideration of parameters like engagement type, terrain and breakpoints. The concept of breakpoints will be explained later. To determine precisely the losses of a particular weapon system, some method of disaggregation has to be employed.

The index number can be viewed as one way to reduce the complex problems that a military force planner encounters to a practicable size.

b. Monte Carlo Simulation

In general, Monte Carlo Simulation is being applied to model small units' actions like infantry fire-fight, anti-tank versus tank or air-defense versus aircraft encounters. Usually, the weapon effectiveness is derived from technical performance data like rate of fire, weapon accuracy and others. By means of conditional kill probabilities describing ordnance effects, kill ratios are calculated. This process usually includes detailed models of detection, identification and target selection. For more details, see the Engineering Design Handbook [Ref. 9].

Modelling in detail produces very complex structures. However, the final product is often more credible to many users--

especially on decision-maker level--apparently because it contains more detail and the inherent assumptions are not apparent (e.g., the often encountered question of a decision-maker: "how do you play smoke?"...). For the same people, however, these models are far too complicated to understand. In addition, they require huge amounts of data as inputs. The source of these data and their updating are of utmost concern for the user of these models and much dedication and detailed knowledge has to be exercised to solve the inherent problems. The use of data received from the manufacturers of weapon systems without further investigation may well lead to deceiving results. A degradation of performance data under operational conditions should be expected. Field trials might be better suited to produce the required data, but this is usually expensive and time-consuming and therefore not always feasible.

The issue of "validity"--often brought up by proponents of detailed modelling--has to be addressed. It is very difficult to include important factors like combat experience or bravery in the detailed model. Comparison with historical data is rarely helpful, since:

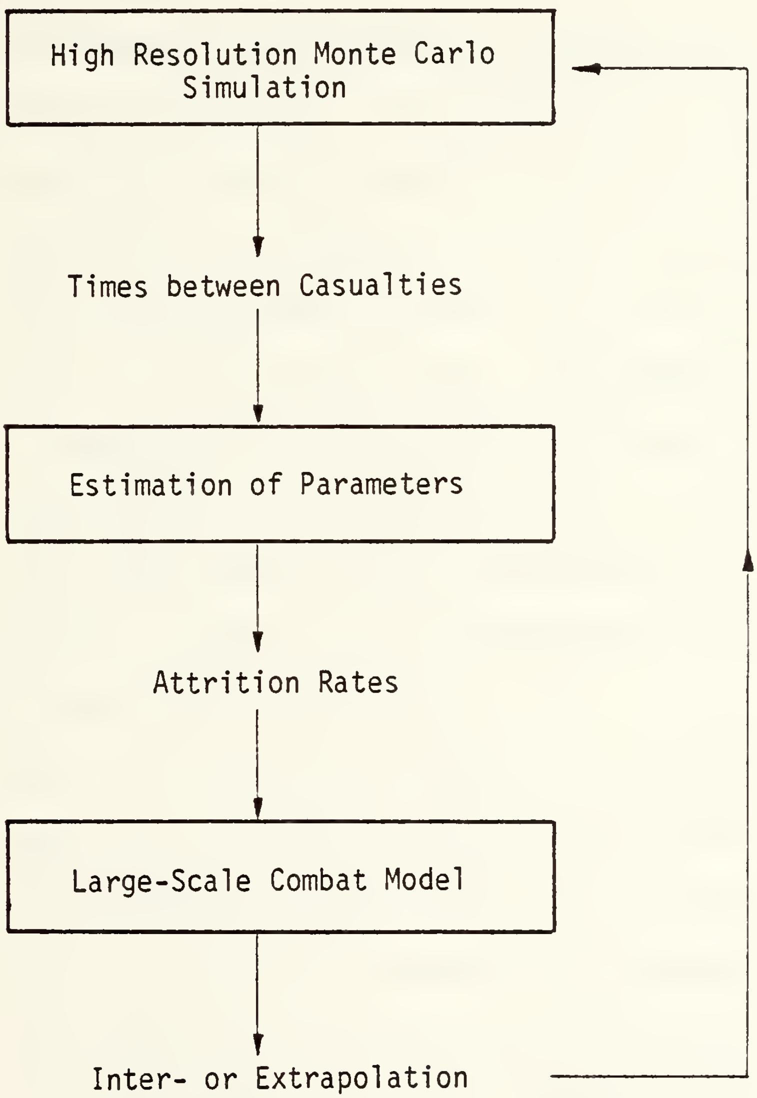
- these data are usually not available in the necessary detail (after all, in our society, it is not acceptable to begin a war just to collect data) and
- many studies are concerned with future weapon systems so that historical data are not available at all. For more details about data base problems, see: Models, Data and War, Report to the Congress [Ref. 10].

One way to model large scale combat using high-resolution Monte Carlo Simulations is the method of "fitted parameter models", the

principle of which is depitced below in Table II. For more examples of the use of Monte Carlo Simulations, see Tschujew [Ref. 11] and Wentzel [Ref. 12: pp. 309f]. For a soviet view of the use of Monte Carlo Simulations as training device, see Wentzel [Ref. 12: pp. 318f].

TABLE II

Fitted Parameter Model (from: [Ref. 8: p. 48])



c. Conclusions

The planning of conventional forces using mathematical modelling and statistical methods is quite common. Combat modelling can be done using different approaches, depending on the scope of research and on its objective. Detailed models treat specific combat interactions, whereas aggregate models are used for large scale confrontation problems and for planning purposes. Some of the key issues are listed below and discussed:

- the firepower index as well as the underlying concept is highly controversial. It usually fails to consider the synergistic effects of combining military units when these units are composed of different weapon systems. The resulting numbers are said to be "valid" only when used in large-scale modelling. The concept of linearity, or equivalently of additivity, of different inputs is questionable. But because of the ease of application and the inherent advantage that the necessary data-bases are smaller, firepower-score representation will be used as one major means for analysis.
- Monte Carlo Simulation, especially in detailed small-scale modelling, is useful as a tool to gain insights in the "micro-cosmos" of war. Additionally, it can be used to verify higher level firepower-score representations. Monte Carlo Simulations are better suited to model details of real-world combat activities, although one has to be aware of their biggest disadvantage, which is the necessity to

establish and maintain large data-bases. This implies, depending on the programming language used, excessively long running times because of a multitude of look-ups in data files.

As Taylor suggests [Ref. 8], detailed models should be used as analytical tools and as aides to determine basic relationships, while simple aggregated models should be used to communicate with decision-makers.

2. The Resource-Allocation Issue and the "Military Production Function"

"The principal shortcoming of the firepower-score approach is its linear quality" [Ref. 1: p. 79]. One could get the firepower-index in Table I also if one employed 32640 soldiers, each of them carrying an M16 rifle. This implies that each of the inputs is a perfect substitute for any other. If this were the case in reality, the problem of optimizing the structure of any military force would be almost trivial. Depending on the constraints, one would employ only the input with the highest marginal product, the highest value of the quotient of firepower-score and cost, commonly called "the biggest bang for the dollar". The resource allocation problem like an "optimal" weapons mix would not exist at all, because there would not be any mixed force.

Reasoning that the marginal product of any input might not be constant, leads to the economic theory and, in particular, to the theory of "production functions". If it were possible to establish a "military production function" and if its form and coefficients were known, the solution for the problem of computing the marginal products would lead directly to the establishment of a combat effectiveness index.

The economic theory of production describes production processes in terms of production functions. The general form of these production functions is:

$$P = f(x_1; x_2; \ldots; x_n) \qquad \text{Eq. 1}$$

It states that a product (P) is a function of various inputs (x_i). These inputs are capital- and labor-oriented. In the military environment, this could be interpreted as equipment and manpower, e.g., tanks or aircraft and soldiers.

One of the many possible forms of this production function is linear:

$$P = \alpha_1 x_1 + \alpha_2 x_2 + \cdots + \alpha_n x_n \qquad \text{Eq. 2}$$

The firepower-score with its linear quality can be viewed as one application of Eq. 2. The variables are assumed to be independent from each other and there exists infinite substitution elasticity between them. For more details concerning linear production functions, see Nicholson [Ref. 13, Chapter 7]. There exist two possible explanations for the linear form of the production function:

- as it stands. The variables are independent and the coefficients are the marginal products. This implies perfect substitutability between them. This would result in a "one specialty force".

- from the application of linear programming techniques. If seen in this context, it would be assumed that to get an output, the inputs must be used in certain, fixed proportions, in concordance with the ratios of the coefficients to each other. As an example for this interpretation in the military environment, one could perceive that a carrier task force has to consist of two attack carriers, three frigates, six destroyers and so on Ref. 1: p. 81 .

Most production functions are of nonlinear form as shown below:

$$P = Ax_1^{\alpha_1} \cdot x_2^{\alpha_2} \cdot \dots \cdot x_n^{\alpha_n} \qquad \text{Eq. 3}$$

$$\text{with } \frac{\partial p}{\partial x_1}; \dots; \frac{\partial p}{\partial x_n} > 0$$

$$\text{and } \frac{\partial^2 p}{\partial x_1^2}; \dots; \frac{\partial^2 p}{\partial x_1^2} < 0$$

One special form of Eq. 3 is known as Cobb-Douglas production function. It is named after C. W. Cobb and P. H. Douglas [Ref. 14: p. 132]. It has the following form:

$$P = A \cdot x_1^{\alpha_1} \cdot x_2^{\alpha_2} \qquad \text{Eq. 4}$$

This equation has proved to be quite useful for many applications, since it can be changed into a linear form:

$$\log P = \log A + \alpha_1 \log x_1 + \alpha_2 \log x_2$$

Considering x_1 to represent equipment inputs and x_2 to represent manpower inputs, α_1 and α_2 are then the elasticities of output with respect to

equipment and manpower respectively. The constants α_1 and α_2 can sometimes be estimated from actual data and the principal form of the production function can be established. For more details, see Nicholson [Ref. 13: p. 199].

The military decision-makers of all times have been concerned--knowingly or not--with the estimation of the form and the coefficients of the military production function. Carl von Clausewitz (1780 - 1831) writes [Ref. 2, Chapter 13]:

> "...since a squadron of 150 horses, a battalion of 800 soldiers and a battery of 8 six-pounders cost equally in procurement as well as in operating cost, the question is...how to find the optimal ratio between them,...since it seems trivial to notice that only a mixture of all weapon systems can give us an advantage in the different situations in a war..."

When he reports that the most successful "force mix" of his time was to employ one eight-gun battery per one thousand to three thousand infantrists and about one quarter as many cavalry as there was infantry, he really assigned certain values to the coefficients of the linear form of the military production function and took into account the relative cost of the respective weapon systems.

Presently, the trend goes towards replacing manpower by equipment to reduce costs and meet certain other constraints. The large-scale implementation of this replacement policy implies the widely shared believe that there exist high substitution elasticities between capital-intensive force elements and manpower-intensive ones. In less complicated language, this means that one can do a certain task equally well using certain equipment when using a certain amount of soldiers. Some force planners do not share this belief. The former German Air Force General Steinhoff warns: "Those who come to rely too much on

technology may find one morning that an army clad in skins and wielding clubs has captured them, lock, stock and Laser".

The widespread use of the linear form of the military production function has many reasons. It is relatively simple and transparent in suggesting that the output is the sum of the inputs which are weighted by a factor representing the marginal capabilities. The weights are frequently determined by judgment and experience and unfortunately not by thorough analysis. However, it can be easily recognized that military production processes are not linear as the use of this form of the production function might imply. The marginal products are frequently diminishing when the corresponding inputs increase above certain limits. On the other hand, some inputs may require a certain minimum input level to generate any output at all. One realization of this reasoning will be presented later in this thesis as a proposed improvement in the SAM-suppression module (see Chapter V.A.). Diminishing returns, as well as the opposite effect described above, can be modelled mathematically by the use of an exponential-additive form of the production function, whose general form is depicted below:

$$P = \alpha_1 x_1^{\beta_1} + \dots + \alpha_n x_n^{\beta_n} \qquad \text{Eq. 5}$$

For β between Zero and One, the resulting function is concave, indicating diminishing returns. The other possibility mentioned above can be depicted by a convex-concave shape of the production function.

Establishing the military production function in its complete form is not a trivial task at all, because:

- one has to determine the form and the coefficients of the function by empirical means. The necessary data for this endeavor cannot be found directly, since wars are not waged, at least not in our democratic society, just to collect data. The primary feasible means to find these data are field trials, exercises and combat modelling. Based on these data, a reasonable estimation can take place to find the form and the coefficients of the function.
- the change of technology shifts the military production function in an unknown way, which necessitates a new evaluation.

Stockfisch reasons that military production processes are frequently multipicative [Ref. 1]. His argument is that the common understanding of expressions like "combined arms" and "joint operations" imply that the respective processes are nonlinear and multiplicative. The general form of this function is shown below:

$$P = Ax_1^{\beta_1} \cdot x_2^{\beta_2} \cdot \cdots \cdot x_n^{\beta_n} \qquad \text{Eq. 6}$$

In this form, the marginal capability of each input depends on the respective levels of all inputs.

All the forms of the military production function presented above model military processes as if they were absorbed by a market. The reasoning behind military buildup is, however--at least in the understanding of the writer of this thesis--not to let this "market" happen. Additionally, this approach to the establishment of the

military production function needs to be modified to represent an aspect mentioned earlier: interactions do not only exist between the different inputs of one side, but also between one side and the inputs of the possible adversaries. To include this aspect, the following general form of the military production function would have to be applied:

$$P = f(x_1, \cdots, x_n, y_1, \cdots, y_m) \qquad \text{Eq. 7}$$

where the x_i and y_i represent the inputs of the opposing forces.

It is apparently not at all trivial to find the proper form of the military production function. Even if one takes the simplest, linear form--as depicted in Equation 2--using the firepower-score representation and modelling attrition with a Lanchester-type approach, the task is not easier. As Taylor points out, the solution by analytical methods is essentially impossible [Ref. 15]. He shows that analytical solutions require the assumption of homogeneity of forces and that for heterogeneous forces, analytical methods are feasibly only if the attrition rates--represented by their coefficients--are constant.

III. THE TACTICAL AIR WAR ANALYSIS GAME (TAWAG)

A. GENERAL APPROACH AND MEASURE OF EFFECTIVENESS

The Tactical Air War Analysis Game (TAWAG) was designed by Taylor and Huber in 1979 [Ref. 7] as a hierarchically structured "quick" game to be used as a cursory tool to check long-range air armament policy options within the context of high-intensity conventional war in Central Europe. The game was later developed at the Federal Armed Forces University (Hochschule der Bundeswehr) in Munich, West Germany, and is presently implemented on a Burroughs B 7700/162 computer system. The programming language was PL/1 in the form of IBM-F-level.

TAWAG should aid in the two interdependent decision-making processes, firstly concerned with the efficiency of deployment of existing Air Forces and secondly with the long-range planning of future force structures. Earlier models used for these purposes used the amount of ordnance delivered as measurement of effectiveness (MOE). Based on the word of Clausewitz that: "war is an act of violence to force our will onto the enemy..." [Ref. 2: p. 89], the main purpose of an Air Force can only be the support of the ground forces in combat. Since the primary objective of combat is to deny the enemy the possibility to invade the country permanently, a reasonable MOE is the relative position of the frontline to the situation at the beginning of the war. In TAWAG, this frontline is called Forward Edge of the Battle Area (FEBA).

TAWAG is an antagonistic multi-stage game which consists of two interacting war-models: the air war and the ground war module. The general model structure is shown in the figure below.

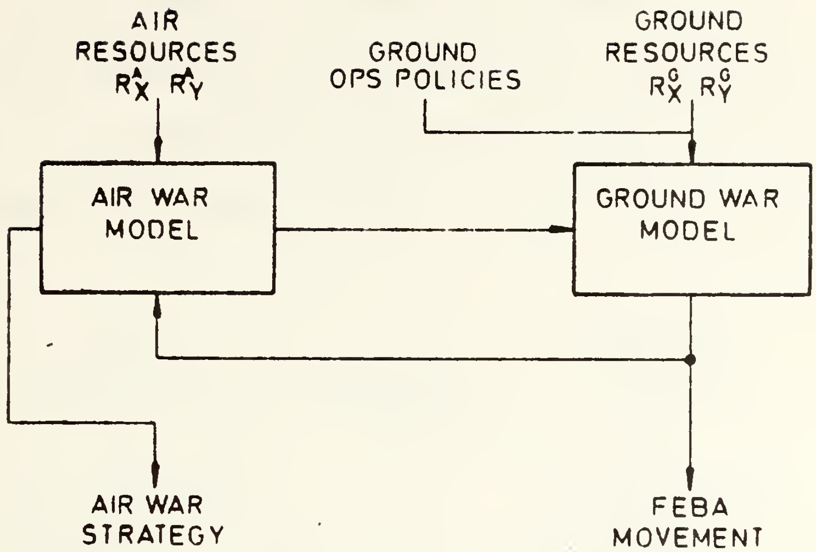


FIGURE 5: Basic Model Structure

The defender tries to minimize the effects of the opponent's attack in such a way as to prevent him from gaining ground, whereas the attacker tries to maximize just that. The inputs to the models are data related to the respective air- and ground-resources, e.g., air weapon systems and their probabilities of success or ground forces and their capabilities as represented by firepower-indices. Additionally, ground-operation policies like deployment or breakpoints are determined beforehand and used as inputs stored in the data base. In the original, the intermediate output, the FEBA-movement, is used as additional input for the air model, to be used to find the "optimal" air war strategy. The present version does not contain the optimizer module, so that the output of the MOE (FEBA-movement) is not fed back

into the air war model. Additionally, the air war strategies are input variables rather than output of the air war model in the latter version of TAWAG. Figure 6 shows the new model structure.

A Lanchester-type attrition is used to model the reduction of the number of air war systems during the course of the war and a firepower-score representation is used to model the ground war attrition.

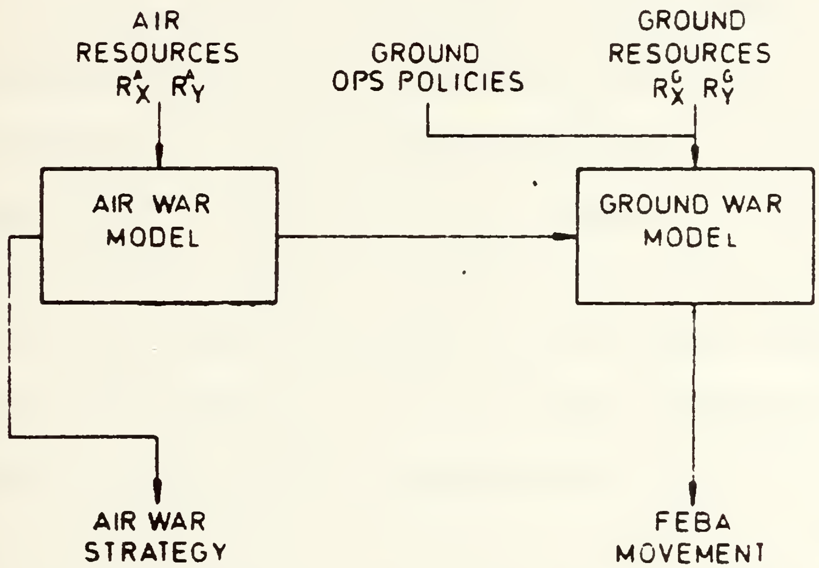


FIGURE 6: Present Model Structure

The reason why the optimizer module was deleted in the second version of TAWAG was mainly a time-economic one. To ensure that an optimum is achieved for the air war strategy, it is necessary to check all possible strategies. To show what dimensions can easily be reached, one should consider the following example. If each opponent has only five possible strategies to choose from in every stage of the game and if the war is modelled to last for ten cycles only, the total number of strategies (N_S) to be checked will be:

$$N_s = 5^{10} \cdot 5^{10} = 9.5367432 \cdot 10^{13}$$

This example shows that it is very time-consuming to perform a total enumeration of all possible strategies. In fact: a run of the original model on the computer system mentioned above showed that a run with only three air war systems and only one air war cycle per combat day consumed 48 CPU-hours [Ref. 16: p. 16]. Seitz proposes one possibility to reduce these excessive running times [ibid.]. The model determines one initial strategy for the first cycle and this strategy is held constant throughout the conflict. This version can be applied when the battle-development is to be evaluated using constant strategies and constant ground battle time when the air war duration is being varied, in other words: find the effect of prolonged air war on the FEBA-movement. The present version considers different predetermined strategies for each "round" of the conflict. The set of these strategies is part of the data base. There exists no guarantee that an "optimal" strategy can be found using this approach. A different possibility to reduce running time by reducing the number of computations so that the optimizer module may be feasible again will be proposed in Chapter VI.

B. THE AIR WAR MODEL

1. Basic Assumptions

In the present model, each opponent can have up to six different types of air war systems, one of which can be unmanned, like a Cruise Missile. The number of air bases is variable and can be predetermined in the data base. Each air base can host only one type of weapon system at a time. The variables influencing the capabilities of an air base are the capacity and condition of the runways and the capacity of the

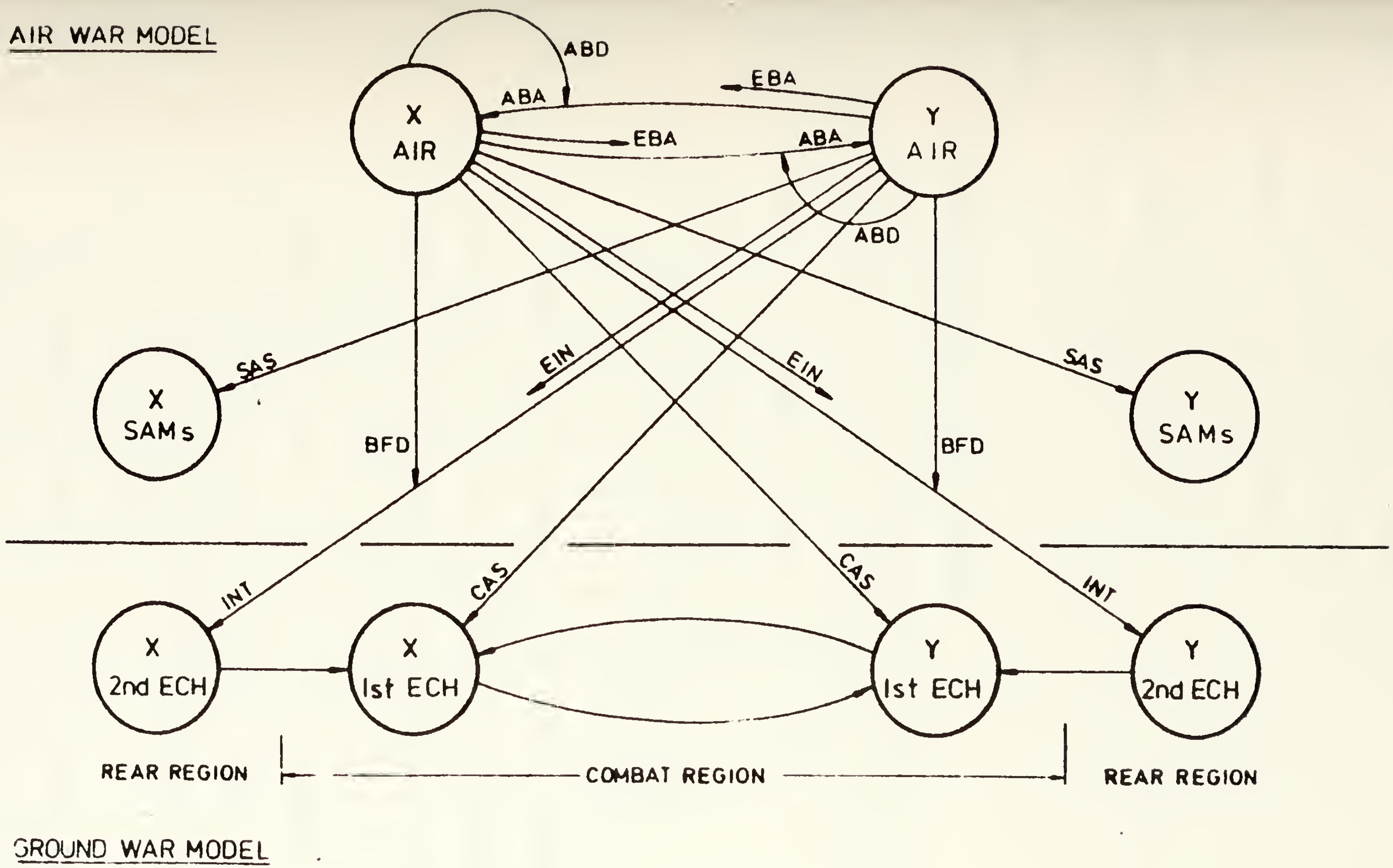


FIGURE 7: TAWAG - Interactions

supply- and maintenance-facilities. All these variables can be changed in value by air attacks and are regenerated at a certain predetermined rate. The aircraft parameters relevant to the model are type, number and capabilities and its possible and actual missions. Each opponent has air-defense in form of surface-to-air missiles deployed in his rear region. These sites can be directly attacked and possibly destroyed or jammed by electronical countermeasures. They are regenerated similarly to the airbases. There is no regeneration necessary after electronical jamming.

2. Air Missions and Weapon Systems

The air war model of TAWAG considers the following missions for air war systems: (for a more detailed description including the mathematical formulae, see Huber and Taylor [Ref. 7]).

a. Offensive Counter Air Role (OCA)

- Surface-to-Air-Missile Suppression (SAS)

  The attack on opposing surface-to-air missile (SAM) sites is the first step within each cycle. Attacks are always initialized by SAS. The amount of SAM-suppression depends on the number of attacking air war systems and is determined by the use of suitable curves that are incrementally stored in the data base (FORTRAN-version). The curve actually used in the present model seems unrealistic and a modification will be proposed in Chapter V.

- Air Base Attack (ABA)

  Attacking the enemies' airfields is the second step in each cycle. The goal of this attack is to reduce the number of

aircraft able to start by destroying the runways and the logistical support.

b. Offensive Air Support Role (OAS)

- Close Air Support (CAS)

  The goal of close air support is to inflict losses to the enemy in the vicinity of the frontline, similar to the effect of artillery fire, so that the ground forces will achieve superiority.

- Interdiction (INT)

  This mission is designed to inflict losses on the reserves or on the "second echelon". It does not show instantaneous results, but reduces the combat-capabilities of reserves on their march to the frontline, so that less firepower will reach the battlefield.

c. Defensive Counter Air Role (DCA)

- Interception for Air Base Defense (ABD)

  This role is designed to fight against weapon systems performing ABA.

- Battlefield Defense (BFD)

  This mission counters weapon systems trying to perform INT- and CAS-missions.

- Escort for Air Base Attack (EBA)

  EBA increases the probability of success for ABA-missions.

- Escort for Interdiction (EIN)

  EIN increases the probability of success for INT-missions.

Each of the air war systems--depending on the type--is capable of performing one or more of these different missions. The possible roles and missions and some examples of deployable weapon systems are depicted in Table III.

3. Survivability and Probability of Success

The probability of success and the survivability are functions of the respective missions. Both are used to calculate the results and effects of the different air war efforts. For the mathematical formulae, see Taylor and Huber [Ref. 7]. The following events are possible during the performance of a mission and have influence on its result:

E1: system survives its mission and is successful

E2: system survives its mission but misses the target

E3: system is "killed" during mission before weapon delivery

E4: system survives an attack on its base but is not able to start for its mission

E5: system is destroyed on the ground

Parallel to these events, one can establish the following possibilities:

P_G: probability of survival on the ground

P_T: probability for take-off

P_S: probability of survival enroute to target

P_D: probability of target detection

The use of the probability of target detection implies the assumption that once a target is detected, it will certainly be destroyed. This does not represent the present state of targeting technology. The user of TAWAG has to be aware of this fact unless he uses it to model future systems which have the capability of "shoot and forget".

TABLE III

Mission Capabilities

Role	OCA		OAS		DCA				
Mission	SAS	ABA	CAS	INT	ABD	BFD	EBA	EIN	Example
Type 1			+						A-10
2					+	+	+	+	F-16
3		+	+	+					F-15
4	+								(ECM)
5	+	+	+	+	+	+	+	+	MRCA
6		+		+					Cruise Missile

A mission is modelled to be successful, if and only if the event E1 takes place. Figure 8 can be used to verify this. The probability of E1 is calculated in the following way:

$$P(E1) = P_G \cdot P_T \cdot P_S \cdot P_D$$

For a proposed enrichment, see Chapter V.

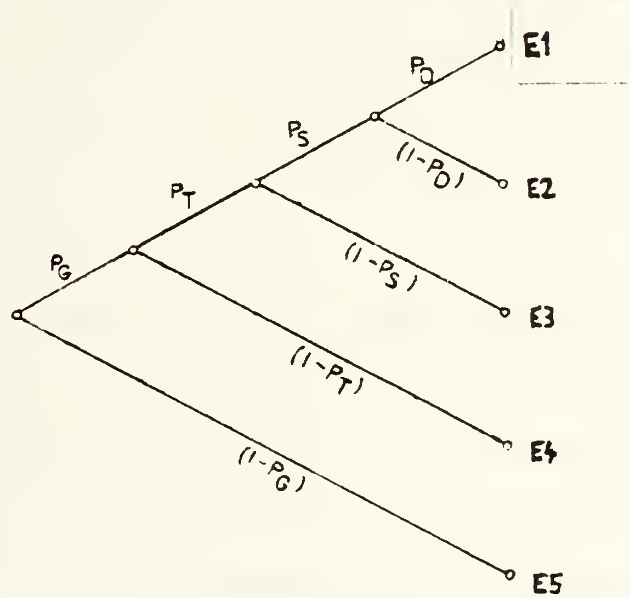


FIGURE 8: Mission Events

TAWAG models two different types of attack-missions against opposing air weapon systems:

- general ABA, where all air weapon systems allocated to ABA-missions are uniformly distributed over all weapon systems of the opponent, and

- concentrated ABA, where all ABA-allocated systems are used against one specified weapon system [Ref. 18: p. 40].

If damage is assessed, a temporary reduction of air war capabilities is imposed on the opponent.

Air weapon systems of type 6 (e.g., Cruise Missiles) do not survive an assigned mission and can therefore be used only once. As stated above, ABA-missions can have a detrimental effect, the same effect that can be achieved against air-defense systems (SAM). The amount of attrition of SAM depends upon the number of attacking aircraft. A linearly decreasing function is used to assess the received damage in terms of fractions of initial strength. After an attack, the regeneration takes place with a predetermined rate per time-unit, until the original strength is regained. A more realistic SAM-suppression curve will be presented in Chapter V.

The effectiveness of air war systems depends on the availability of logistics and maintenance support; as well as on the status of the runways. This influence is modelled in the following way:

- the capacity of the logistic and maintenance support is included in the establishment of the sortie-generation rate, and
- the capacity and availability of runways is included in the probability of take-off.

Successful CAS and INT sorties against ground forces are directly included in the calculation of a reduced firepower-index for the respective forces.

C. THE GROUND WAR MODEL

1. The Battlefield

The battlefield is divided into sectors, the number of which can be specified by the user of TAWAG. The sectors can be thought to lie parallel to the main direction of attack. The principal geometry of the model is depicted in Figure 9.

The frontline (FEBA) is the line where the opposing ground forces meet. Initially the FEBA is located on a demarcation line from which the penetration is calculated in both directions. On both sides of the FEBA are the respective combat regions. Ground combat takes place exclusively within these regions. Adjacent to the combat regions are the respective rear regions. Reserves or the "Second Echelons" have to be assembled there prior to marching to the front.

As stated earlier, the task for the attacker is to maximize penetration into the regions of the defender, and conversely, the task for the defender is to minimize this penetration. Superimposed on the geometrical model of the battlefield is a terrain model which divides each sector into successive bands of three possible types of terrain trafficability. The three types used are:

- normal terrain
- reinforced terrain
- minefields

The terrain has an influence on positions and movement of troops. Each sector can have its specific terrain-features, independent of the adjacent sector. Within these segments, the terrain is homogeneous.

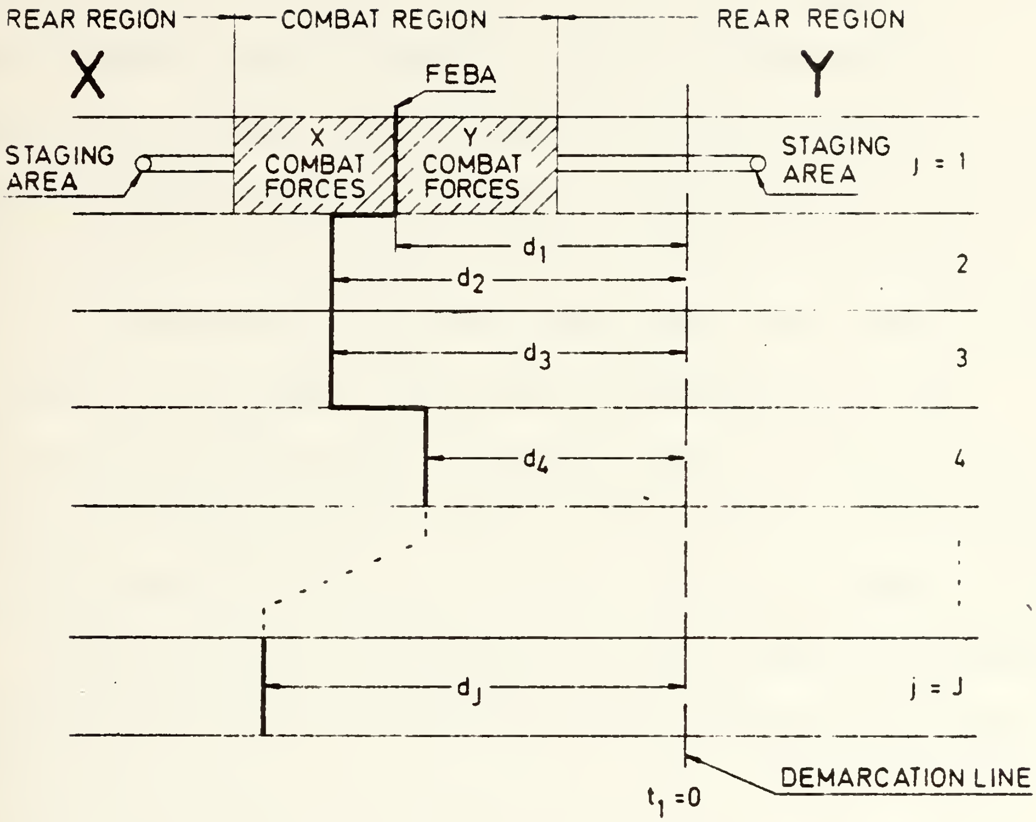


FIGURE 9: Battlefield Geometry

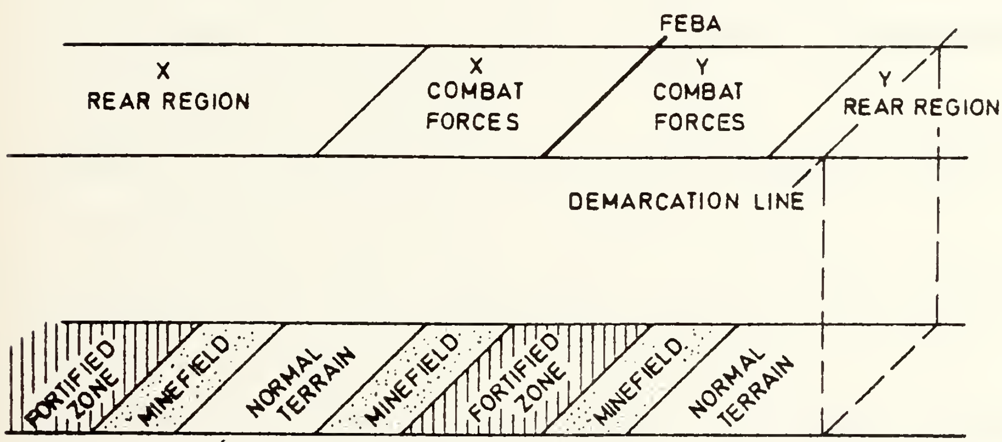


FIGURE 10: Terrain Representation

2. Combat Capabilities

The ground war model considers each sector as an individual, independent process. This means that the model cannot represent a continuous frontline, running through the borderlines between sectors. The reasoning behind this modelling aspect is the desire to analyze the influence of different tactics on an otherwise constant war model and to be able to compare results directly without resorting to repeated runs.

At the beginning of a conflict, both sides have a certain number of divisions to be employed. A division is the smallest unit considered in the ground war model. The capabilities of each division is described by a firepower-index. The principles involved in the establishment and the problems of the use of firepower-indices have been discussed above. All divisions on each side have the same strength at the beginning of a conflict. The divisions are placed at the front and in the rear staging areas.

The total number of divisions will not change throughout the battle, although their firepower-indices are subject to attrition. A division can be in one of the following states [Ref. 17: p. 34]:

- disassembled in the rear region, which makes it invulnerable to interdiction attacks;
- assembling in the staging area in the rear region, which makes it susceptible to attacks;
- marching to the front, which makes it vulnerable by interdiction-attacks;
- at the front, attacking, which makes it vulnerable to close air support and subjects it to attrition by the opposing ground forces;

- at the front, defending, which makes it vulnerable to close air support and subjects it to attrition;
- at the front, retreating, which subjects it to the same threats as described in the two cases above;
- replaced by reserve-divisions, which eliminates all threats to attrition.

It is assumed that the divisions on one side (Y, "RED") are replaced as a whole when their "strength" reaches a certain predetermined level. (For details, see next Chapter.) In this way, all divisions in one sector can be treated as one large unit as far as replacements are concerned. The reserve divisions of the other side (X, "BLUE") are moved to the front individually, as soon as they are assembled in the staging area. This procedure necessitates the tracking and bookkeeping of individual divisions on this side. The actual position of the troops is relevant only if they are in a defensive role.

Only three classes of positions are modelled in TAWAG and have an influence on the "strength":

- fortified positions
- prepared positions
- hasty defense

3. Combat Processes

Combat is modelled to consist of three processes:

- command and control
- attrition
- movement

Command and control is represented by a logic structure to simulate tactical decisions. "Breakpoints" are used to establish the

points in time when a division can no longer attack and must change to a defensive role. In each sector, one single mission is determined for all Y-divisions, while individual missions have to be found for each X-division. For calculational purposes, X-divisions with the same missions are combined to one "unit" by adding their respective firepower-indices. The designation of missions to divisions is depicted in Figures 11 and 12 below.

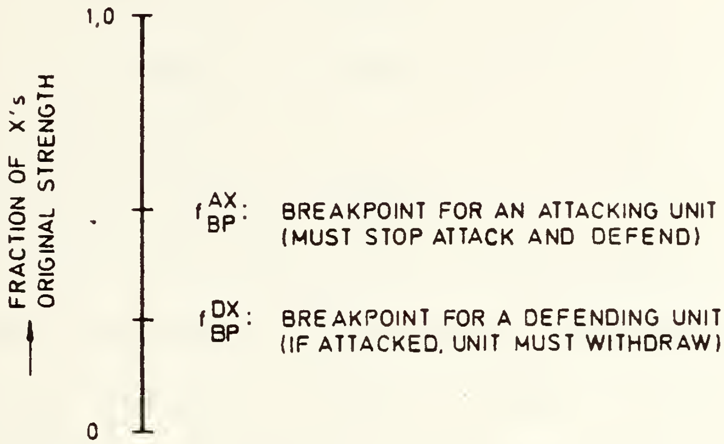


FIGURE 11: Unit Breakpoints for X-Force

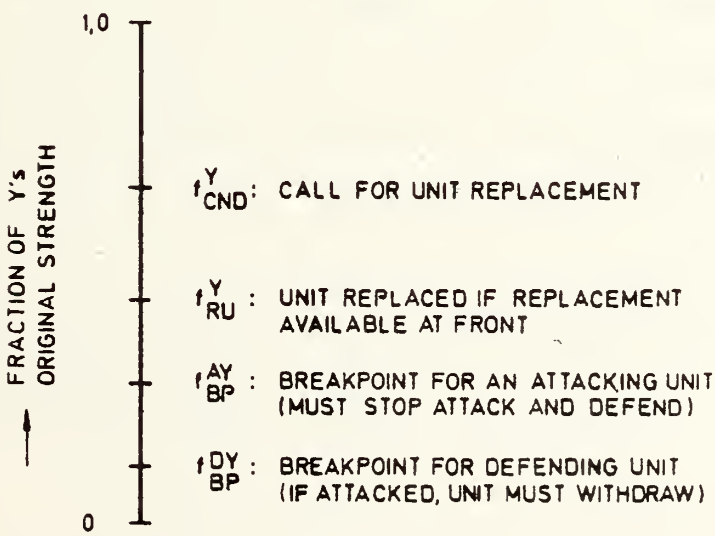


FIGURE 12: Unit Breakpoints for Y-Force and Committing of Reserves

Using the assigned missions and the type of defensive positions of the respective units, an engagement type is determined using the dependencies depitcted in Table IV [Ref. 7: p. 54].

There are different possibilities to model attrition [Ref. 8]. TAWAG models two different types of attrition, the one caused by the opponent's air war systems and the one inflicted by ground forces.

Enemy air attack (INT and CAS)--attrition is modelled in the following way: each air war system has an assigned firepower-index which it will "destroy" if its mission is successful. The total attrition depends on the number of successful sorties and will be distributed evenly among all opposing divisions. INT is modelled to be the only reason of attrition in the rear region.

Attrition in the combat regions is calculated as a function of the force ratio and the type of engagement. ATLAS-curves are used to assess the daily casualties, depicted in Figure 14 [Ref. 8].

FEBA-movement is dependent on the force-ratio, on the engagement type and on the type of terrain within the combat zone. It is derived from curves similar to those discussed by GOAD in: "The Modelling of Movement in Tactical Games" [Ref. 5: p. 199]. It is important to notice that these curves are difficult to verify and GOAD states that: "The connection (to historical data)...is extremely tenuous, not to say non-existent". As an illustration of the fact that analysts in different nations develop and use widely varying movement rates, the figure below is presented [Ref. 5: p. 206].

TABLE IV

Engagement-Type Determination

X Mission	Y Mission:	Attack	Defend			Delay	Withdrawal
	Position Type	-	Hasty	Prepared	Fortified	-	-
Attack	-	Meeting Engagement	X Attack of HD	X Attack of PD	X Attack of FD	Delaying Action	Withdrawal
Defend	Hasty	Y Attack of HD	S	S	S	S	-
	Prepared	Y Attack of PD	S	S	S	S	-
	Fortified	Y Attack of FD	S	S	S	S	-
Delay	-	Delaying Action	S	S	S	S	-
Withdrawal	-	Withdrawal	-	-	-	-	-

Note: In the above figure: S = Static;
HD = Hasty Defense;
PD = Prepared Defense;
FD = Fortified Defense.

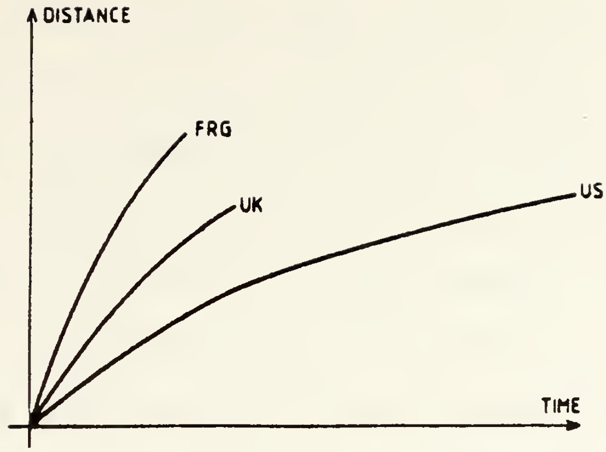


FIGURE 13: Attacker Advance Rates

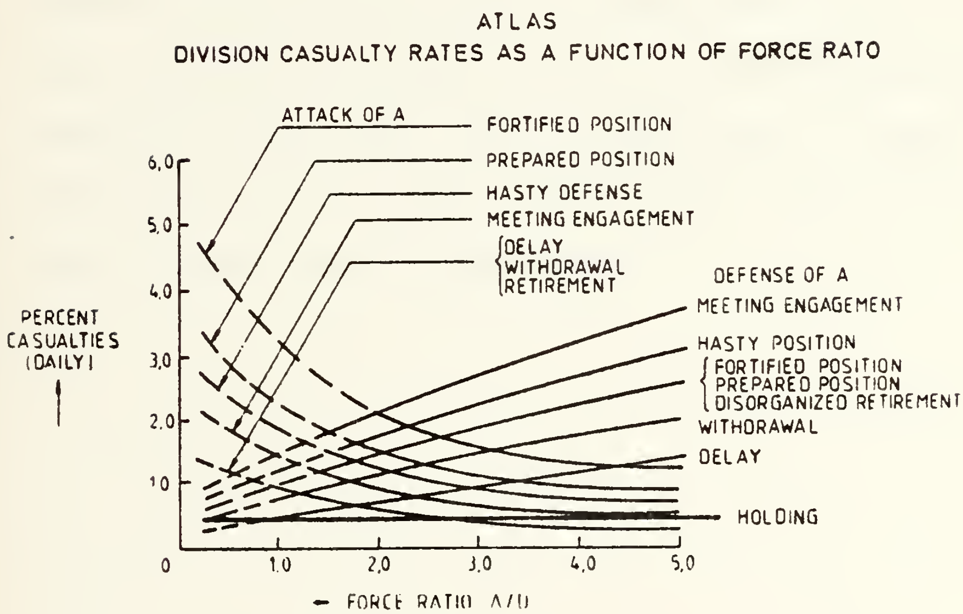


FIGURE 14: ATLAS - Casualty Rates

The deployment of reserves is modelled in the following fashion:

- Y-reserves are initially scattered in the rear area, waiting for a "request" from the front. As soon as the divisions on

the front reach the level f^{Y}_{CND} (call for unit replacement), a number of divisions equal to the ones fighting at the front is assembled and started on the march to the front. The marching speed is predetermined and their firepower-index is subject to attrition by INT-sorties. If the breakpoint f^{AY}_{BP} or f^{DY}_{BP} is reached, the front-divisions are replaced. If not, all reserve-divisions have reached the front, the new firepower-index of Y is averaged using that of the reserve-divisions and that of the ones not replaced.

- In contrast to the Y-divisions, the X-divisions in reserve reach the rear area at a given rate. As soon as they arrive in this area, they begin to assemble and after a predetermined time, they march to the front. Their firepower-index is subject to attrition. Arriving at the frontline, they replace the divisions with the lowest firepower-index.

IV. SYNOPSIS OF ATTEMPTS TO TRANSFER THE TAWAG MODEL TO THE NPS-COMPUTER

The writer of this thesis was introduced to the concepts of TAWAG in the early Summer of 1980, when he had the opportunity to talk with Professor H. W. Hoffman (Federal Armed Forces University, Munich, W. Germany) who was visiting the NPS at that time. The writer was interested in working on an operational model, especially as pertains to defense planning in W. Germany, and was willing to accept the challenge to implement TAWAG on the computer system of the NPS, although the computer program was not too well documented. The distant possibility that TAWAG could be used as a teaching device for combat-modelling courses further invited the selection of this topic as thesis-work. Professor James G. Taylor encouraged the writer to choose this subject and made him aware of possible pitfalls.

The existing version of TAWAG used PL/1 as programming language, of which the writer had only rudimental knowledge. Nevertheless, the studies done during the Fall-quarter led to the detection of possibilities for improvement and enrichments.

Knowing that the IBM-360 system of the NPS would be changed to the newer 370-system, it was decided not to start programming until the new system was installed and operational. Additionally, it was not known at that time what implications the new system would have with respect to the implementation of TAWAG. Although the new system brought improvements for the user--especially the use of terminals with CRTs--those did

not apply for PL/1-programming which still had to be done in batch processing. This was cumbersom, considering the size of the original PL/1-version of TAWAG. It consists of 4328 lines of code and needs twelve data-files of considerable size and complexity.

For a few weeks during the Winter-quarter 1980, the feasibility of a change of the programming language to SIMSCRIPT was checked. This effort was abandoned in favor of the implementation of a FORTRAN-version, based on a thesis by Droll [Ref. 18]. Four months (including the Summer-break) were used to change the program to a form compatible with the IBM-system in use at the NPS. During these efforts, it became apparent that a program listing alone is not sufficient as a basis to implement a complex computer model like TAWAG, since it does not show the peculiarities of the computer system it comes from.

Based on these efforts, some suggestions are made in Chapter VI to improve the general transferability of computer models and to help alleviate these problems for future similar projects. In the first weeks of the Summer-quarter 1981, it was decided to change the scope of this thesis to its present form.

V. PROPOSED IMPROVEMENTS AND ENRICHMENTS

A. SAM-SUPPRESSION

As presented above, TAWAG models SAM-suppression-effects of SAS-missions using a linear reduction function. The independent variable of this function is the number of attacking air weapon systems (AWS), the dependent variable is a number between Zero and One, representing the relative remaining strength of the SAM-capability, as depicted in Figure 15.

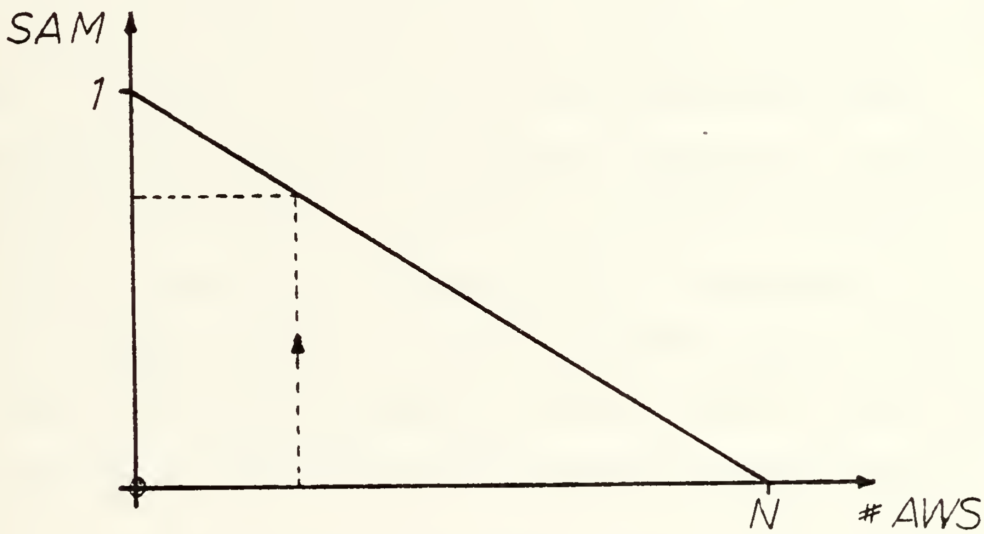


FIGURE 15: SAM-Suppression

N represents the number of AWS necessary to reduce the effect of SAM-missiles to Zero. This number varies, depending on the type of attacking AWS.

Two objections to this way of modelling are presented here.

- In a real-world situation, only a few SAM-sites will be attacked at a time, specifically those which are perceived as a major threat along the main attacking routes. This is intended to increase the probability of success for OCA and OAS missions. The model should be modified to represent this type of attack-tactic.
- The linear form of the curve does not seem to represent the real world either. One of the more successful ways to fight SAM-sites is to saturate the fire-control capability, either electronically, or by the sheer number of attackers. This implies that a minimum number of AWS is necessary to cause some initial degrading effect. Additionally, it can be perceived that the cumulative suppression-effect is not linear, or more specific, that there is a reduction in suppression-effectiveness for each additional attacker if their number is increased. This leads to the proposed improvement.

The proposition is to change the reduction function to a nonlinear form as depicted in Figure 16. The number n_E represents the number of AWS up to which no reduction of SAM-capabilities is noticeable. N is the number of systems necessary to reduce the effectiveness of the SAM-systems to Zero. The function between n_E and N is convex (as seen from below) to indicate the decreasing "rate of return" in effectiveness of attackers.

Using the PL/1-version of TAWAG, this suggested improvement is not trivial to implement, since this version uses a closed form of this reduction function. An approximation of this closed form might be necessary to establish. The present form of the applicable PL/; code is: [Ref. 17: "card image listing"].

```
IF ANZ XF(TYP) THEN RETURN((XF(TYP)-ANZ)/SF(TYP))
```

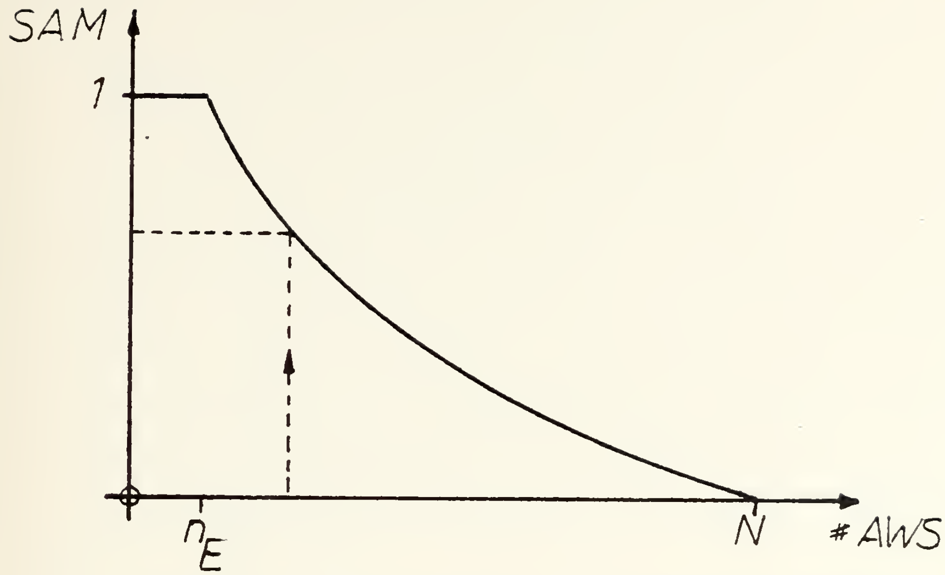


FIGURE 16: SAM-Suppression (Improved Version)

Using the FORTRAN-version of TAWAG, it is not necessary that the exact mathematical form of the reduction-function is known, since it is stored pointwise in the data base. However, the algorithm to find the interpolated value of the reduction function imposes a severe limitation to the proposed form. The relevant part of the algorithm in FORTRAN-code is listed below [Ref. 18: p. 92].

```
STUETZ + YALT+(ANZ-XALT)*(Y-YALT)/(X-XALT)
```

The division by Zero which would occur as long as the number of AWS is smaller than n_E in the linear horizontal part of the proposed reduction function can be avoided if this part of the reduction function is put into the data base as a linear, slightly decreasing function, as depicted in Figure 17.

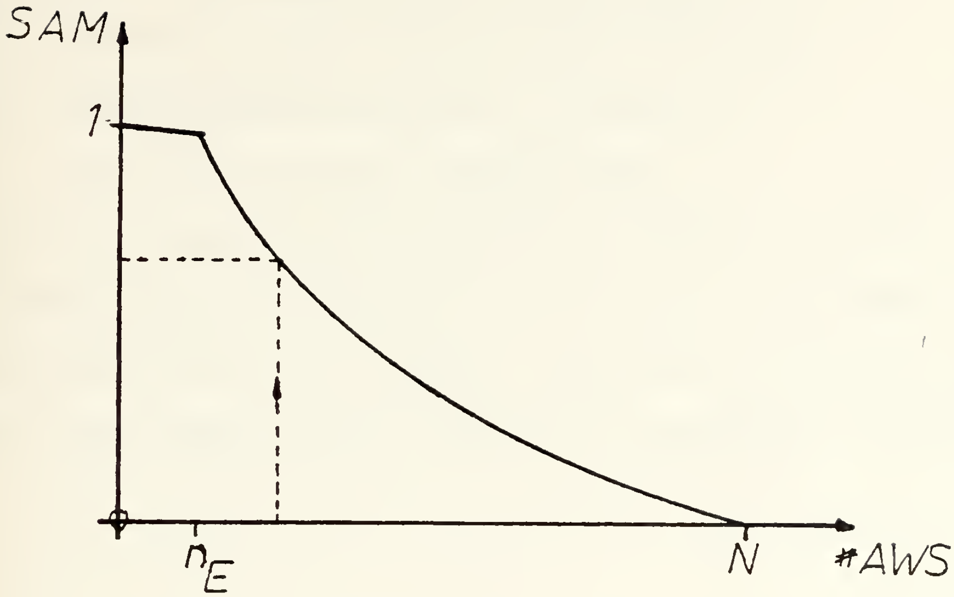


FIGURE 17: SAM-Suppression (FORTRAN-Version)

This way the present FORTRAN-version of TAWAG can be used essentially unchanged. A different way to implementing the proposed improvement would necessitate an additional coded statement to check if the number of attacking AWS is smaller than n_E and if this is the case, to return the value One for the reduction function.

B. SURVIVABILITIES OF AIR SYSTEMS

As stated above, the survivability of AWS--excluding type 6, which can be used only once (it represents Cruise Missiles)--is calculated using the formula:

$$P(E1) = P_G \cdot P_T \cdot P_S \cdot P_D$$

This formula does not include the possibility that an aircraft is shot down after successfully attacking the target. To include this

possibility, the list of possible events should be changed to include an event E0. The proposed event-list would look like this:

E0 = successful attack, AWS does not survive return

E1 = system survives mission and is successful

... (and so on, as shown in Chapter III)

The event E1 is used as before to assess attrition to the enemy, but additional calculation is necessary to find the correct number of AWSs available for future use. The actual formulation of this calculation depends on the TAWAG-version at hand and the programming language used.

VI. RECOMMENDATIONS AND CONCLUSION

Increased application of Operations/Research-methods for planning problems on all levels of the military hierarchy has led to the development of a great (and ever increasing) number of complex models. If a user does not have a thorough understanding of all assumptions and implications, erroneous conclusions can be drawn and may conflict with results achieved from other models. It is therefore absolutely crucial that adequate documentation exists, if a model is to be used by anybody else but its developer, especially if it is fairly complex, since increased complexity results in diminished transparency. The author's experiences in this thesis effort support the importance of this demand.

Szymczak [Ref. 19: p. 72] has proposed that three different types of documentation be established before an attempt is made to transfer a model:

- a non-technical model description for decision-makers,
- extensive conceptual-technical documentation for analysts, and
- technical information for those programmers who try to transfer a model to a different computer.

Establishing these three different sets of documentation and their update is often perceived as a tedious, unnecessary task, especially during the development-phase of a model. However, the lack of one of them may well lead to such problems, that the efforts to transfer a model are abandoned and a new modelling effort is started from scratch. Considering this costly alternative, the establishment of proper documentation seems to be worthwhile.

The author feels that more work should be done on the selection of criteria by which air operations are evaluated, i.e., the MOEs used for optimization in TAWAG. Currently, TAWAG uses FEBA-movement as single MOE. As pointed out earlier, the functional connection between force-ratio and front-movement is difficult to establish. Therefore, it seems to be reasonable to include losses or loss rates as additional MOE, since a combination of occupied ground and total numerical losses or loss rates determine the willingness of each opponent to end combat actions. Dupuy has suggested three MOEs to quantify battle outcomes [Ref. 20: p. 42]:

- the extent to which each side accomplished the assigned or perceived mission,
- the ability of each side to gain or hold ground, and
- the efficiency with which each side did these two things in terms of casualties.

The author suggests further investigation, possibly using the considerations mentioned above as a point of departure, of the evaluation criteria in TAWAG.

One drawback of the present version of TAWAG is the inability to find the optimal strategy--if it exists. In the first model, the optimal strategy was found in the optimizer-part by means of total enumeration of all strategies. This part has been deleted from TAWAG to reduce running time to a feasible length and to be able to predetermine strategies. An inclusion of a "filter" to eliminate impossible strategies could reduce the total number of alternatives to be checked in such a way as to regain feasibility of running time. Additionally,

it could be possible to achieve shorter running times by employing a different method of optimization.

Special attention should be focused on the establishment of the data base for TAWAG. Using the original data base, Haardt [Ref. 17: p. 202] found out that CAS-sorties have no measurable effect on the FEBA-movement. This seems counter-intuitive. He traced this back to the choice of certain values in the data base. It could also possibly be attributed to the fact that CAS does not have a direct influence on rate of FEBA-movement (i.e., a shortfall of model formulation). The author suggests that the reason for this "anomality" should be investigated.

Combat modelling is a potentially very valuable tool, although its use can cause a lot of controversy. Some of the problems and possible pitfalls have been pointed out in Chapter II. Knowing and evaluating these problems, a military analyst can gain insights in the nature of war and the interdependabilities of the factors contributing to it. It seems important to notice again that combat modelling itself does not make decisions, but that it can influence and assist decision-makers by making them aware of trade-offs and cost-differences between alternatives. Results of model-runs can be misleading if apparent or implied assumptions are unrealistic, or if some essential constraints are unknown or uncertain. The latter is specifically valid for the prognostic character of data used to evaluate future weapon systems in time frames of ten or twenty years. This implication of uncertainty is always one element of planning--if one uses operations research methods or not--and the military decision-maker has to live with it.

Another frequently encountered problem should be mentioned in passing: the reliability of modelling results is also dependent on asking the "right" questions.

The biggest problem, however, seems to be the link of communication between the analyst and the decision-maker. As Hoz points out (in: Huber [Ref. 5: p. 219]), trust in the method and comprehension of models in use can improve this communication.

This thesis is intended to represent one step to achieve just that.

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